The Pennsylvania State University

LionTech Rocket Labs

2018 - 2019 Solium Project

Proposal

046 Hammond Building, University Park, PA 16802
September 19th, 2018

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List of Acronyms

A&R	Avionics and Recovery
CFD	Computational Fluid Dynamics
EIT	Electronic and Information Technology
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
EHS	Environmental Health and Safety
GPS	Global Positioning System
HPCL	High Pressure Combustion Lab
LTRL	LionTech Rocket Labs
MDRA	Maryland Delaware Rocketry Association
MSDS	Material Safety Data Sheet
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
PPE	Personal Protective Equipment
PSC	Pittsburgh Space Command
PSU	The Pennsylvania State University
RSO	Range Safety Officer
SDS	Safety Datasheet
SLI	Student Launch Initiative
STEM	Science Technology Engineering and Mathematics
STTR	Small Business Technology Transfer
TRA	Tripoli Rocket Association
UPAC	University Park Allocation Committee
USLI	University Student Launch Initiative

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1. General Information

1.1 Team Summary

School Name
Pennsylvania State University

Team Name and Address
Lion Tech Rocket Labs: 236 S Barnard St, Unit 3, State College, PA 16801

Team Leader
Gregory Schweiker – gfs5113@psu.edu (215) 870-6719

Adult Educator
Dr. David Spencer - dbs9@psu.edu (814) 865-4537

NAR Contact/Mentor
Justin Hess NAR L2 Certification - #102887 – jthess418@gmail.com

NAR Sections
Pittsburgh Space Command (PSC) #473
Maryland Delaware Rocketry Association (MDRA)

1.2 Team Roster and Structure

LionTech Rocket Labs will have a team that consists of about 50 active members throughout the year. These members are undergraduate students pursuing various STEM degrees between freshman and senior year.

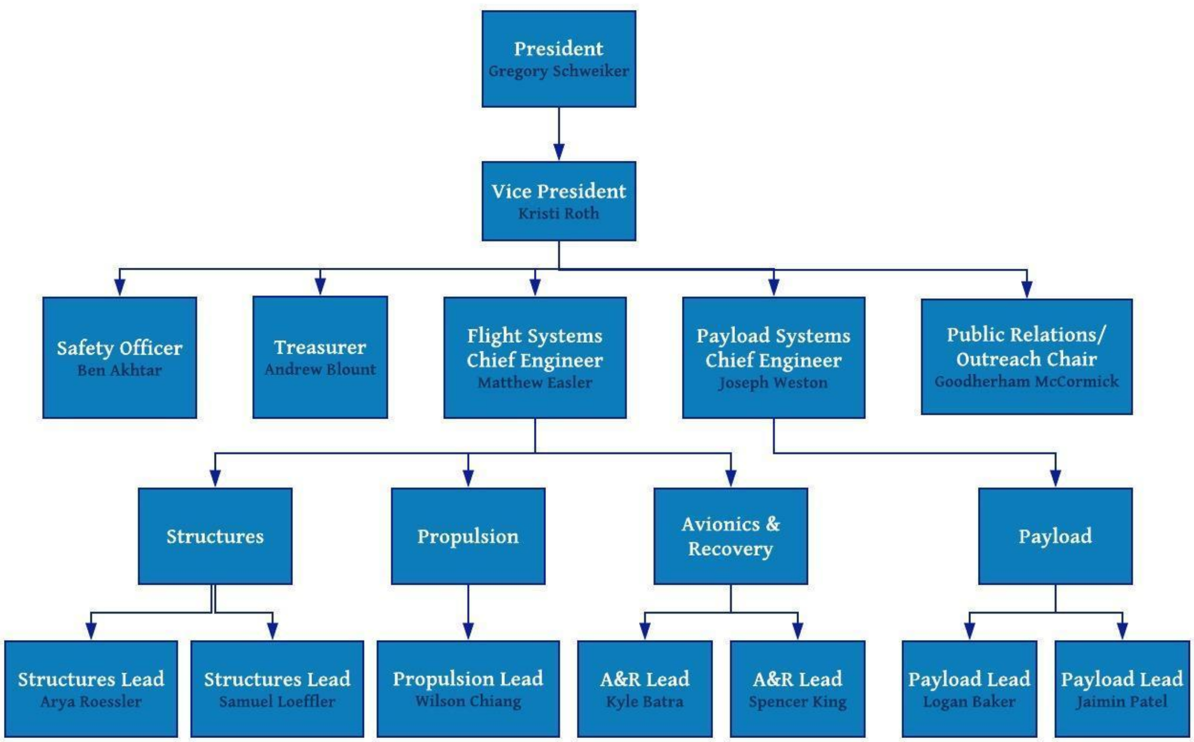


Figure 1. Team Structure

The team is run by 13 leadership positions that are organized as shown in Figure 1. Four of these positions are president, vice president, treasurer, and safety officer who are responsible for managing the team and handling administrative business. The president, Gregory Schweiker, is in charge of keeping the team on schedule, staying in touch with mentors and advisors, and leads weekly meetings. The vice president, Kristi Roth, assists the president with his duties, ensures integration between all subsystems, and communicates with general body members. The treasurer, Andrew Blount, takes on the task of raising club funds. He budgets the organization's money, holds fundraising events, updates the club's donors, and arranges meetings with new, interested sponsors. The safety officer, Ben Akhtar, oversees subsystems' safety plans and coordinates general body members' safety courses. The Public Relations/Outreach chair, Gooderham McCormick, is responsible for photographing the design, build, and test processes, updating the club's social media and website, and planning outreach events to share LTRL's involvement in the STEM field.

The rest of the leaderships' roles carry out the technical branch which is broken up into two systems, Payload Systems and Flight Systems. Payload Systems is led by the Chief Payload Engineer, Joseph Weston. He maintains integration between Payload Systems and Flight Systems, makes executive payload decisions, and supervises two other payload leads: Jaimin Patel and Logan Baker. The payload leads are responsible for the design, build, and functionality of the project specific payload.

Flight Systems is headed by the Chief Flight Systems Engineer, Matthew Easler. He upholds integration with Payload Systems and Flight Systems, carries out executive flight vehicle choices, and oversees the three subsystems that the system is divided into: Structures, Avionics and Recovery, and Propulsion. Structures has two leadership positions held by Arya Roessler and Samuel Loeffler. Their duties are to design and create the flight vehicle, test materials, ensures all necessary components are compatible for the flight vehicle, and supervise vehicle assembly on launch day. Avionics and Recovery constructs the rocket's avionics bay and tests ejection charges, altimeters, and parachutes. On launch day, they are in charge of proper parachute packing and successful vehicle recovery. Propulsion is led by Wilson Chiang who selects the motor and runs flight simulations.

2. Facilities and Equipment

2.1 Facilities

LTRL Lab

The LTRL student lab is located at 046 Hammond Building at the University Park campus of the Pennsylvania State University. The lab houses the equipment and hardware used by the club for the duration of the competition. Access to the lab is available to club leads Sun-Sat from 8:00 am to 11:00 pm. General members can access the lab whenever there is a lead in the lab. Materials and tools in the lab are organized into toolboxes and storage containers for easy access. Most subsystems hold weekly meetings in the lab except in cases that the lab does not offer enough seating. A rough diagram of the lab is shown in Figure 2.

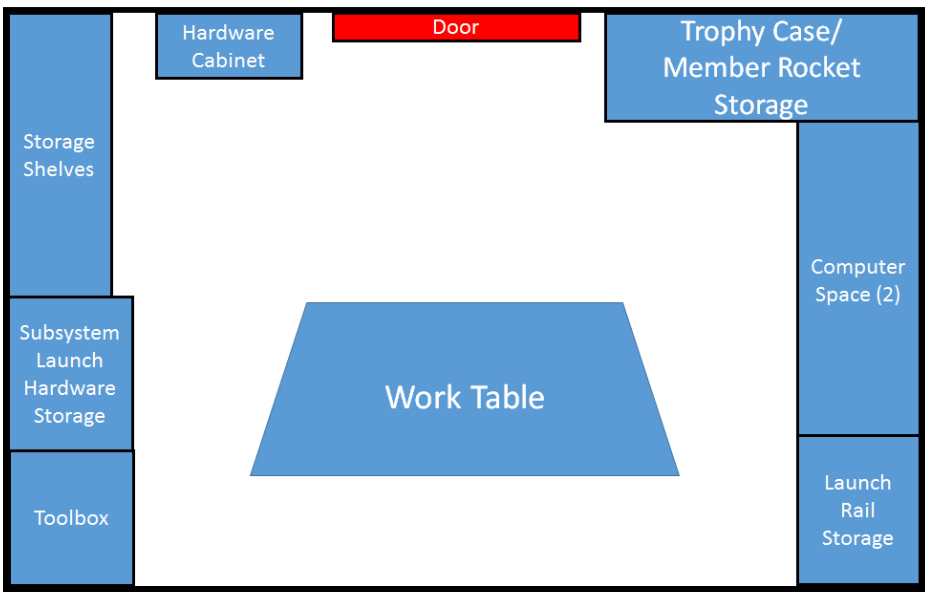


Figure 2. Layout of LTRL Lab

Penn State Learning Factory

The Penn State Learning Factory is an on-campus machine shop that students can use for their projects. Any student is free to use the shop if they have gone through the Learning Factory certification process. Several club members have a Learning Factory certification. The Learning Factory can be used to access standard machining equipment as well as other tools like high fidelity 3-D printers. Club members often go to the Learning Factory to machine larger or more complex custom components. The Learning Factory is open Mon-Fri 8:00 am to 10:00 pm.

Aerospace Machine Shop

The Aerospace Engineering Department and LTRL have recently reached an agreement to allow some LTRL members to use the Aerospace Machine Shop. This machine shop is located a few rooms away from the LTRL lab and is therefore more convenient for club members to use than the Learning Factory. The Aerospace Machine Shop features most basic shop tools. For safety, club member can only use the machine shop in the presence of a trained staff member from the Aerospace Department.

High Pressure Combustion Lab

The High Pressure Combustion Lab (HPCL) is a research facility at Penn State. The HPCL has class 1.1 and 1.3 explosive storage bunkers on their property. LTRL has asked and been granted permission to store rocket motors in the HPCL storage facilities. The HPCL also has reinforced bunkers and specialized test facilities for high pressure combustion systems. The Propulsion subsystem uses these facilities for competition motor testing. A&R also uses the HPCL grounds to test ejection charges for the subscale and full scale rocket.

Penn State Computer Labs

Penn State has multiple computer labs throughout campus with specialized engineering software like SolidWorks and MATLAB. These labs are used for computer aided drafting and design (CAD) as well as computational fluid dynamics (CFD) and finite element analysis (FEA).

2.2 Equipment

Avionics and Recovery

The personnel required to construct and handle the avionics and recovery systems include members who have been trained in shop floor safety and basic shop tool use. Experienced members will be familiar with proper parachute packing methods as well as ejection charge handling. Basic hand tools and power tools will be used in the construction of the Avionics bay by personnel who have completed the required safety training. The supplies needed for this subsystem include:

- Stratologger SL100/CF altimeters
- 9V batteries
- Steel all-threads
- Plywood bulkheads
- U-bolts
- Quicksnap connectors
- Blast caps
- Nylon shear pins
- Parachutes
- Kevlar blankets
- Kevlar shock cord
- Steel quick links
- Black Powder
- Fireball

Structures

The personnel required for the overall construction of the flight vehicle includes club members with knowledge of advanced manufacturing techniques. This includes training in basic power tools, hand tools, lathe machines, mill machines, and experience in additive manufacturing. To construct the final flight vehicle, necessary supplies include:

- Fiberglass or Blue tube body tubes
- Carbon fiber wrapping

- Nosecone
- Body tube couplers
- Fiberglass fin sheets
- Epoxy screws
- Steel or aluminum all thread rod
- Centering rings
- Bulkheads
- Custom manufactured parts from:
  - Aluminum stock
  - Steel stock
  - Plastic filament ABS or PLA

Propulsion

The personnel required for handling solid rocket motors are club members who have previous experience and NAR certification in the preparation and launching of model rockets. These club members are trained specifically in the steps needed to prepare, pack, and ignite solid rocket motors. On launch day, the propulsion lead heads this job to provide maximum safety while handling the motors required for launch. The supplies required by propulsion include:

- Final selection rocket motors
- Motor casing (full scale and subscale sizes)
- Motor retainer
- Test firing stand
- E-matches

Payload

The personnel required to design and assemble an autonomous rover include team members with skills in programming, electronics, mechanics, and design. Basic power tools and hand tools will be required to construct the frame of the rover. 3D modeling software knowledge is required for the wheels and the electronics bay. The supplies required to build the rover include:

- Wheels
- Aluminum rods
- Wire cables
- Arduino Uno microcontroller
- Servos
- LoRa RFM9x Radio Modules
- GPS
- 9V Batteries
- Lithium ion batteries
- 3D printed containment mechanism
- Dual shaft DC motors
- Motor Drivers
- Fiberglass

3. Safety

Safety is of the utmost importance during high-powered rocketry and the SLI competition. Since there are safety risks that often occur during the entirety of the SLI competition, the Safety Officer and LTLR have come up with a safety plan to ensure that everyone remains safe during the process of construction, testing, and launches. This includes the process of identifying and mitigating past, present or future hazards.

While many of the anticipated hazards are expected on launch days, testing and construction can pose many risks of their own and must be mitigated. Many of these risks come from working with power tools, hazardous materials, or potentially hazardous particulates. To mitigate these risks, all construction of the rocket will occur within room 046 of the Hammond Building, LTRL's designated lab space, or the Bernard M. Gordon Learning Factory, Penn State's machine workshop.

However, meetings will occur outside of the laboratory to discuss project plans, design components, and write reports. In addition to limiting the construction to the designated lab space or the Learning Factory, only members who have passed Laboratory Safety training by Penn State's Environmental Health and Safety (EHS) may enter the lab. To work in the Learning Factory, additional training must be passed under the supervision of the Learning Factory staff. If members have not passed Penn State's EHS training, they may still participate in design work, but cannot do any construction or enter the lab. Furthermore, general members will be supervised at all times by subsystem leads or executive members. The Safety Officer will also attend and supervise subsystem meetings to ensure the highest of safety standards are upheld. Finally, only executive members or subsystem leads have key access to the lab, and general members are not allowed to enter or remain in the lab without proper supervision.

Basic construction techniques of the rocket such as cutting or drilling of materials will be allowed. However, more complex construction will be performed in the Learning Factory. This is to ensure that complex construction is under the supervision of the both the Safety Officer and trained professionals for the safest environment possible.

The primary hazards associated with the selected materials are due to inhalation of small fibers from substances such as fiberglass or carbon fiber. Face masks are provided to all members working in the LTRL lab. Whenever any of the aforementioned materials are being cut, drilled, or sanded, face masks are required to be worn by any member in the lab at that time. A full assessment of anticipated risks can be found in Appendix B. The severity of risks is based on the combination of likelihood and impact, which were quantified according to the scale given below in Appendix A. To reduce these risks, mitigations are proposed which shall reduce either the likelihood or impact of the risk.

3.1 Safety Officer Responsibilities

Ben Akhtar is the Safety Officer for LionTech Rocket Labs for the 2018-2019 SLI competition. As Safety Officer, he is responsible for the overall safety of every team member involved in all parts of the SLI competition. Additionally, he has to make sure the team follows and adheres to all laws and regulations at the local, state, and federal levels. The responsibilities for the LTRL Safety Officer are as follows:

- Write and maintain a safety manual that includes FAA laws, NAR and TRA regulations, safety procedures and plans, Personal Protection Equipment requirements, hazards, and mitigations of those hazards containing Safety Data Sheets (SDS) for all hazardous substances used at any point during the construction, test, or launch of the rocket
- Ensure all members understand and follow all laws, regulations, plans, procedures and hazards presented in the safety manual
- Ensure all team members have completed Penn State EHS Laboratory Safety training
- Maintain a list of members that have completed safety training, and only allow members who have completed safety training into the lab
- Enforce the proper usage of PPE during construction, tests, and launches of the rocket
- Brief all members on launch safety and NAR/TRA regulations before each launch and ensure they adhere to these regulations
- Monitor and oversee the design, construction, testing, and launching of the rocket to notice and mitigate or remove any possible safety risks or hazards that arise
- Ensure compliance with university regulations, local, state, and federal laws, NAR and TRA regulations
- Maintain launch and safety checklists and ensure that they are taken to every launch to provide proper safety procedures on launch day
- Oversee any and all ground tests of any rocket developed by LTRL and ensure that all procedures are properly followed to minimize risk
- Develop a plan to ensure complete compliance and safety when buying, storing, using, or transporting any energetic devices
- Approving all STEM engagement activities to ensure proper safety for all persons at these events and teach students in the role of safety

3.2 NAR Regulations

Table 1 describes every component of the NAR High Power Rocket Safety Code and how LTRL plans on complying with every rule or regulation.

Table 1. NAR Safety Codes and LTRL's Policies to Follow the Code

NAR High Power Rocket Safety Code	LTRL Policy to Follow the Code
1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only NAR motor certified team members or Justin Hess, the team's NAR mentor will be allowed to purchase, handle, pack, or deal with the appropriate rocket motors.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The structures subsystem will consider and select materials that follow this guideline while factoring in the weight, strength, durability, and other factors in their selection.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any	All motors will be purchased from professional, certified sellers such as AMW Pro-X. All motors and black powder are

purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	stored in the High Pressure Combustion Laboratory (HPCL), which is equipped with a type 4, indoor, portable BTFE explosives magazine. The lab that holds the motors is locked, and the area where the magazine is located in is only accessible to members with the proper NAR certification. Only appropriate motor certified NAR members shall be allowed to handle the rocket motors.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	To ensure proper safety protocol, the Range Safety Officer will have final say over any possible issues with the ignition system on launch day. Additionally, to ensure that charges do not go off prematurely, the altimeters will not be armed until on the launch pad. Finally, all launch vehicle designs will feature key switches to arm any avionics.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	Only the Range Safety Officer or Safety Officer of LTRL may disconnect the battery or remove the launcher's safety interlock. The Safety Officer will remind all members of LTRL of this on the launch site and ensure all members stand a safe distance away until the rocket has either fired or been completely disconnected for at least 60 seconds.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not	The Safety Officer will alert the team and the public before countdown begins to ensure proper awareness of the launch and safety risks. LTRL will make sure to comply with the NAR's Minimum Distance Table and follow any other rules given by the Range Safety Officer on the day of the launch. Additionally, the team will be in compliance with all the other stated rules and ensure proper stability of the rocket for safety and proper flight.

fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	LTRL and the Safety Officer will ensure to use the rails provided by the NAR at any launches and the competition. Furthermore, LTRL and the Safety Officer will ensure a proper launch angle and that there are no fire hazards below or near the exhaust of the rocket motor.
8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	LTRL will select a motor that does not exceed this total impulse limit.
9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	Weather conditions and wind conditions will be checked before each launch to ensure that LTRL follows these guidelines. If there is a possible safety risk, the team will not launch their rocket at that time. Additionally, the Safety Officer will ensure throughout the construction of the rover that no flammable objects could exist to create a flight hazard. The team will ensure that all launches have adequate FAA waivers in place for the rocket launch.
10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power	All launches will be at NAR/TRA events. All launches will be at either Maryland Delaware

lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	Rocketry Association (MDRA) or Pittsburgh Space Command (PSC). If any issues arise, the Range Safety Officer will have the final say over any decisions to launch at that site.
11. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will ensure that the NAR sites they launch at comply with this rule, and that any issues will be immediately brought to the Range Safety Officer. The Range Safety Officer will have the final say over any decisions to launch at this site.
12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The Avionics and Recovery subsystem will design, construct, and test to ensure that all avionics bays are safe for flight use. All rockets will use a full redundant dual deployment system with a drogue and main parachute. Additionally, only Kevlar recovery system wadding shall be added to the rocket. The Avionics and Recovery subsystem will also follow the launch day checklist to prevent any issues that may arise before launch. If any issues arise that cannot be fixed properly, the team shall not launch.
13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	LTRL will make sure that if necessary, proper professionals are contacted to retrieve the rocket.

3.3 Safety Briefings

All LTRL members are required to take Penn State's initial lab safety training. This training is given via four online modules: Introduction to Safety, Chemical Safety, Hazardous Waste Management and Disposal, and Emergency Preparedness. Successful completion of each module requires passing a quiz at the end by achieving a score of 80% or higher. All leads must complete the initial lab safety training online training, and a subsequent session presented by a Penn State Environmental Health and Safety staff member.

Before working with any hazardous chemicals or materials, the Safety Officer will teach and review how to appropriately handle each material and what safety measures are required when using that material. Additionally, a copy of the lab's Unit Specific Safety Plan, including the SDS for all chemicals and hazardous materials used in the lab, is available to members.

Before each launch, the safety officer will conduct a safety briefing to inform all members of the necessary safety procedures and inform all members of NAR regulations. Additionally, the NAR regulations may be found in the safety manual created by the Safety Officer. All members are encouraged to read the safety manual before each launch.

When necessary during the project, verbal caution statements are included in plans for specific meetings in which hazards are encountered. Accompanying the caution statements are the relevant precautionary strategies to protect all involved participants. All warnings and procedures are explained to members before starting work and ensuring all involved parties understand and comply with safety requirements. These safety requirements include the required PPE for the specific task or hazard.

3.4 Cognizance of Laws and Regulations

LTRL is cognizant of and will abide by the Federation Aviation Administration (FAA) regulations regarding the use of airspace, the Code of Federal Regulation 27 Part 55 regarding the handling and use of low-explosives, and the National Fire Protection Association (NFPA) 1127 Code for High Power Model Rocketry regarding fire prevention. All flight testing will occur at the launch sites of established high-power rocketry clubs and an FAA flight waiver will already be in place.

To be sure that the team members are abiding by the aforementioned laws, in addition to university regulations governing possession of black powder, motor testing, static fires, and energetic recovery systems, all testing will be performed under the supervision of and within the facilities of the HPCL located on campus. All tests will be done under the supervision of the Safety Officer and a worker at the HPCL to ensure safe techniques when testing.

All test launches of the competition rocket will be performed during scheduled launch events of MDRA or PSC or another NAR sanctioned club. MDRA and PSC both have strong safety records for many years. Both have multiple qualified Range Safety Officers that will help ensure all laws are being abided by. Club activities related to launches and propellant occur under the supervision of subsystem leads or executive members with the proper level of NAR certification or Justin Hess, the team's mentor, who possesses a level 2 certification from the NAR.

3.5 Purchase and Storage of Motors

All motors and black powder are stored in the High Pressure Combustion Laboratory (HPCL), which is equipped with a type 4, indoor, portable BTFE explosives magazine. The lab that holds the motors is locked, and the area where the magazine is located is only accessible to members with the proper NAR certification. All of these precautions are to ensure proper safety protocols when storing and handling the LTRL rocket motors.

3.6 Range Safety Statement

LTRL will comply with the range safety inspection done by the Range Safety officer (RSO). The team understands that the RSO has the final say on rocket safety issues and that the RSO may deny the launch of the rocket for any possible safety issue. The team also agrees to comply with the safety requirements of the competition and the range safety officer. The team understands the regulations aforementioned and will abide by the stated regulation.

4. General Information

4.1 Flight Vehicle Structure

Vehicle Materials

The airframe material for the rocket this year was chosen with a standard design selection matrix, which is Table 2 located below. The four categories considered were creating carbon fiber tubes using shrink tape, creating carbon fiber tubes using vacuum bagging, purchasing blue tube body tubes, or purchasing fiberglass body tubes. Baking body tubes in an oven or autoclave was not considered due to a lack of necessary tools or sufficient working space. A lower score was given to the shrink tape process compared to the vacuum bagging process due to the manufacturing methods required to create carbon fiber tubes using shrink tape. The team estimates shrink wrapping carbon fiber tubes will result in a more inconsistent distribution of epoxy across the layup than vacuum bagging carbon tubes would. This estimation is based on the results of the team's experiences last year where the shrink tape process resulted in noticeably poor epoxy distribution in the layup. By vacuum bagging carbon fiber tubes, the epoxy will be more evenly distributed, and any excess epoxy will be wicked out. Using blue tube for the flight vehicle would suffice as it is lower in cost, easy to work with, and very safe to use. However, the team has experienced critical blue tube zippering failure in the past.

Table 2. Selection Matrix for Body Tube Material

		Carbon Fiber (Shrink Tape)		**Carbon Fiber (Vacuum Bagging)**		**Fiberglass**		**Blue Tube**	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Strength	0.15	3	0.45	5	0.75	4	0.60	1	0.15
Cost	0.10	3	0.30	1	0.10	2	0.20	5	0.50
Workability	0.10	2	0.20	1	0.60	3	0.30	5	0.50
Material Weight	0.15	3	0.45	4	0.60	1	0.15	4	0.60
Educational Value	0.25	5	1.25	5	1.25	2	0.50	1	0.25
Safety	0.25	2	0.50	3	0.75	1	0.50	5	1.25
Total	1.00		**2.95**		**3.55**		**2.35**		**3.25**

This year, the team decided to place a large focus on the educational value building the flight vehicle will bring to its team members. With the increased use of composite materials in the aerospace industry, the team decided to build the flight vehicle mostly out of carbon fiber. This will require more testing and research than years before. However, the team believes the knowledge gained will be beneficial for years to come.

Last year, the team used carbon fiber wrapped blue tube for the flight vehicle. While carbon wrapped blue tube was sufficient, the team would like to reduce weight, reduce cost, and increase the strength of the flight vehicle by solely using carbon fiber. Current members have experience using carbon fiber with shrink tape, but alternative techniques such as vacuum bagging are being considered. Based on the material selection matrix presented above, the flight vehicle's material will be carbon fiber made using vacuum bagging. However, as no current members have experience vacuum bagging cylindrical tubes, further testing will be required before making a final decision.

Vehicle Dimensions

The full scale rocket expects to be 120 inches long, have a 6-inch outer diameter, and weigh 31.6 pounds with the motor. This results in a static stability margin of 3.07 calibers. The center of gravity and the center of pressure are located 76 inches and 94 inches respectively, aft of the tip of the nose cone. The OpenRocket model of the rocket can be seen in Figure 3.

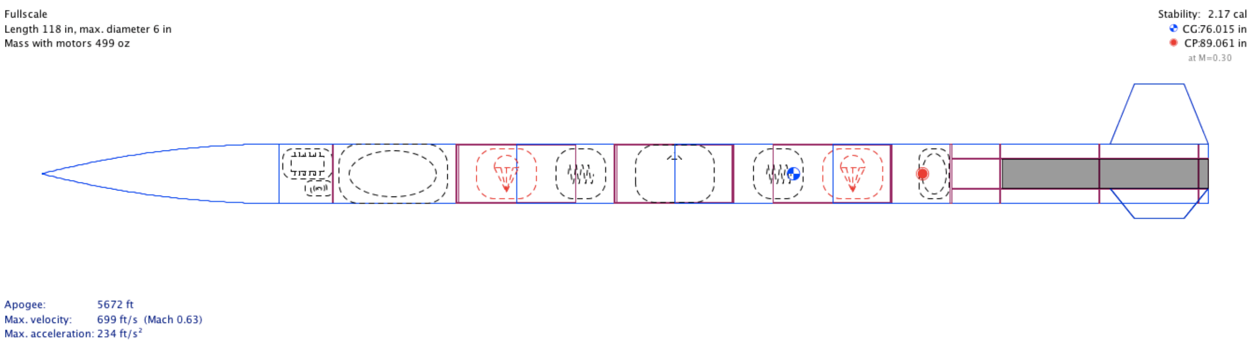


Figure 3. OpenRocket Model

Technical Challenges

The major technical challenge that LTRL will face this year is building the flight vehicle only using carbon fiber for structural support. There will be testing to determine if the carbon fiber tubes can withstand the loads it will encounter during flight. Vacuum bagging cylindrical carbon fiber tubes will also prove to be a major challenge as current members have no experience vacuum. While no members have experience vacuum bagging cylindrical tubes, a few members do have experience vacuum bagging other carbon fiber parts.

Last year, the team was able to drill and cut holes in the carbon fiber because the blue tube that supported the tubes provided sufficient thickness to drill and cut through. However, without the blue tube, cutting holes in the carbon fiber may cause stress concentrations and weaken the structure of the rocket. The team plans to address this by supporting the carbon fiber with blue tube or another body tube insert while cutting and drilling to decrease the chance of potential splintering of the carbon fiber. Additionally, the team will design and use rounded corners on key structural features such as the fin bracket inserts to lower stress concentrations.

Construction Methods

The rocket will be constructed using traditional methods used in high power rocketry. Airframe tubing and fins will be cut to size on vertical and horizontal band saws. Carbon fiber tubes for the body will be made by either the shrink tape process or the vacuum bagging process. To create the carbon fiber tubes using the shrink tape process, a blue tube with the right diameter will be wrapped by epoxy infused carbon fiber wrapping, and then heat shrink taped and heated to harden the epoxy. In order to get the carbon fiber tube off of the blue tube, a waxy substance will be applied to the blue tube before the carbon fiber is wrapped. The process using vacuum bagging is similar, but the tube with carbon fiber will be sealed airtight by a vacuum pump instead. A vacuum will be run to a small incision in the bag, and the extra epoxy will be wicked out onto breather cloth. Epoxy will be applied throughout the rocket as a bonding agent. Construction will be completed in a well ventilated lab by members certified by Penn State to use applicable tools and machinery. During the construction process, all members in the lab will be required to wear safety glasses and respirator masks. Those who are handling material will also be wearing hand protection. The team will use the previous year's 3D printed fin bracket design such that they can be mounted with only screws and bolts as opposed to attaching them with steel resin epoxy. The current design features a slotted rear centering ring to allow the fin brackets to slide into place and be screwed down tight. The current design is shown in Figure 4.

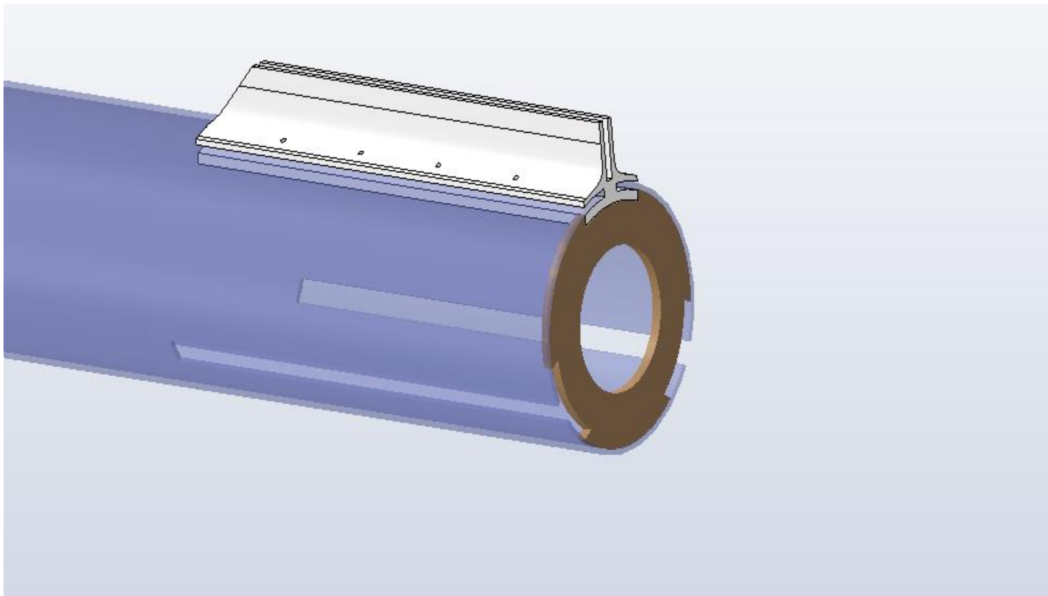


Figure 4. SolidWorks Fin Bracket Model

4.2 Propulsion

Motor Selection and Designation

Preliminary motor calculations were made using the software program OpenRocket to estimate the class of the motor and determine baseline designations. As per competition regulation 2.24.2-2.24.7, the model is based on a single stage motor and shall not be a hybrid, clustered motor, include forward firing motors, or motor that expels titanium sponges. The current estimation for the motor is an L890SS-P motor from Cesaroni, with an impulse of 3695 N•s. This is in accordance with requirement 2.16 of maintaining an impulse of L-Class or lower.

The motor selected will be from the manufacturer Cesaroni, and will utilize ammonium perchlorate composite propellant, in accordance with regulation 2.14. The selected motor is able to be launched utilizing a 12-volt firing system as mandated by regulation 2.12.

Based on the preliminary rocket model, the selected motor will achieve an estimated apogee of 5672 ft. The estimated rail exit velocity is 73.6 ft/s, complying with regulation 2.18, and the estimated stability off the rail is 2.35 calipers, complying with regulation 2.17.

The technical challenges for the propulsion subsystem this year will be to develop an accurate drag estimation program that will be based on subscale wind tunnel testing and full scale test flights.

4.3 Avionics and Recovery

Recovery Plan

For the 2018-2019 competition year, the rocket will use a fully redundant dual deployment recovery system in compliance with requirement 3.1. The drogue parachute will be deployed by a black powder charge ignited by an initiator at apogee. This igniter will be ignited by a current from the on board altimeter. This will separate the rocket into two sections at the first separation point and deploy the estimated 24” diameter parachute. Then, at 700 feet above the ground, the main parachute estimated to be 84” in diameter will deploy through the same method at the second deployment point. The main parachute will be large enough to slow the rocket to a landing velocity where the largest body tube section will impact the ground with less than 75 ft•lbs of force required by the competition regulations. The parachute recovery system for the flight vehicle is pictures in Figure 5.

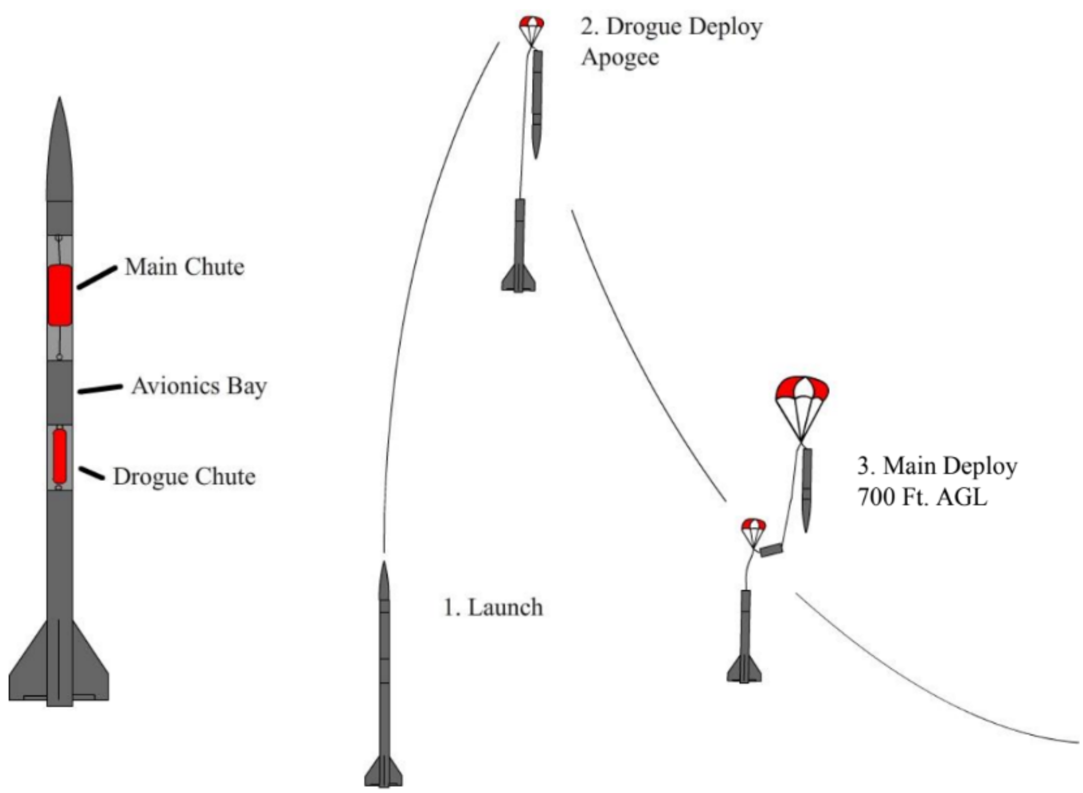


Figure 5. Rocket Recovery Plan

Avionics Bay Design

The initial design for the avionics bay is based on the success of the team's 2017-2018 design. The AV bay will be modeled in SolidWorks, then 3D printed and assembled in the team's lab. The improvements on last year's design are in the placement of the altimeters and the clips that hold the batteries in place, as well as wire positioning.

The avionics bay coupler will hold an aluminum faraday cage. The surrounding bulkheads will also be lined with aluminum. The parachutes will be connected to U-bolts on wooden bulkheads with 3/8" quick links and 1/2" shock cord. The shock cord will be of appropriate lengths such that the rocket sections do not hit into themselves during descent and that the parachutes do not tangle. The initial avionics bay design, shown in Figure 6, is a 3D printed bay that is similar to the one that was successfully used in the 2017 SLI competition.

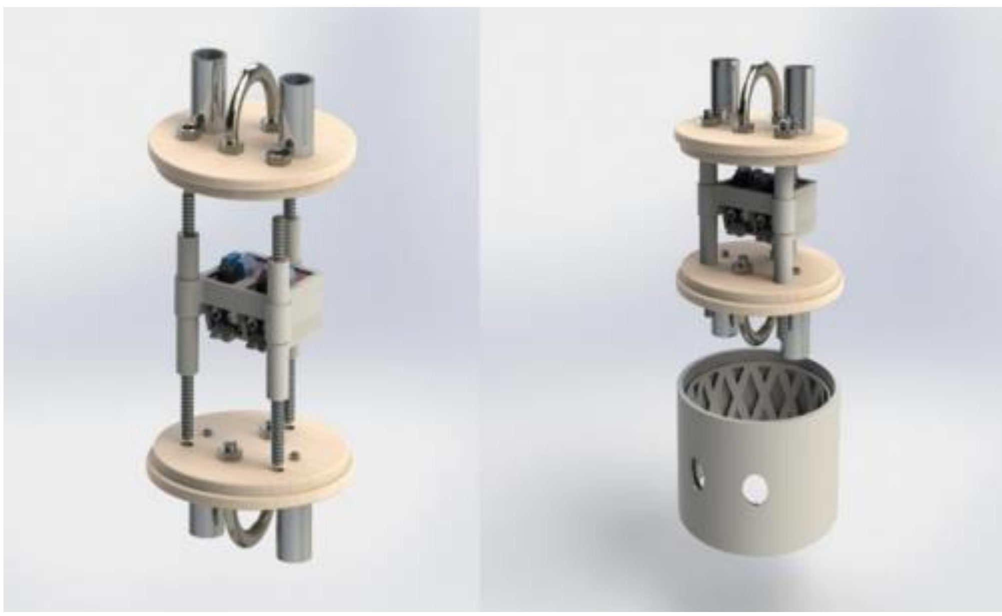


Figure 6. 2017 SLI Avionics Bay

Exploded view (Left), Assembled avionics bay without coupler (Right)

Figure 7 features the AV bay's unique 3" by 2" cutout through the body tube. This cutout has been designed to allow the tray inside of the AV bay to slide out on rails for quick wiring of the altimeters and batteries before launch. The cover of this tray will be a section of body tube that will be screwed on before flight. This cover will feature a small hole in the center which allow the atmospheric pressure to be measured by the altimeters.

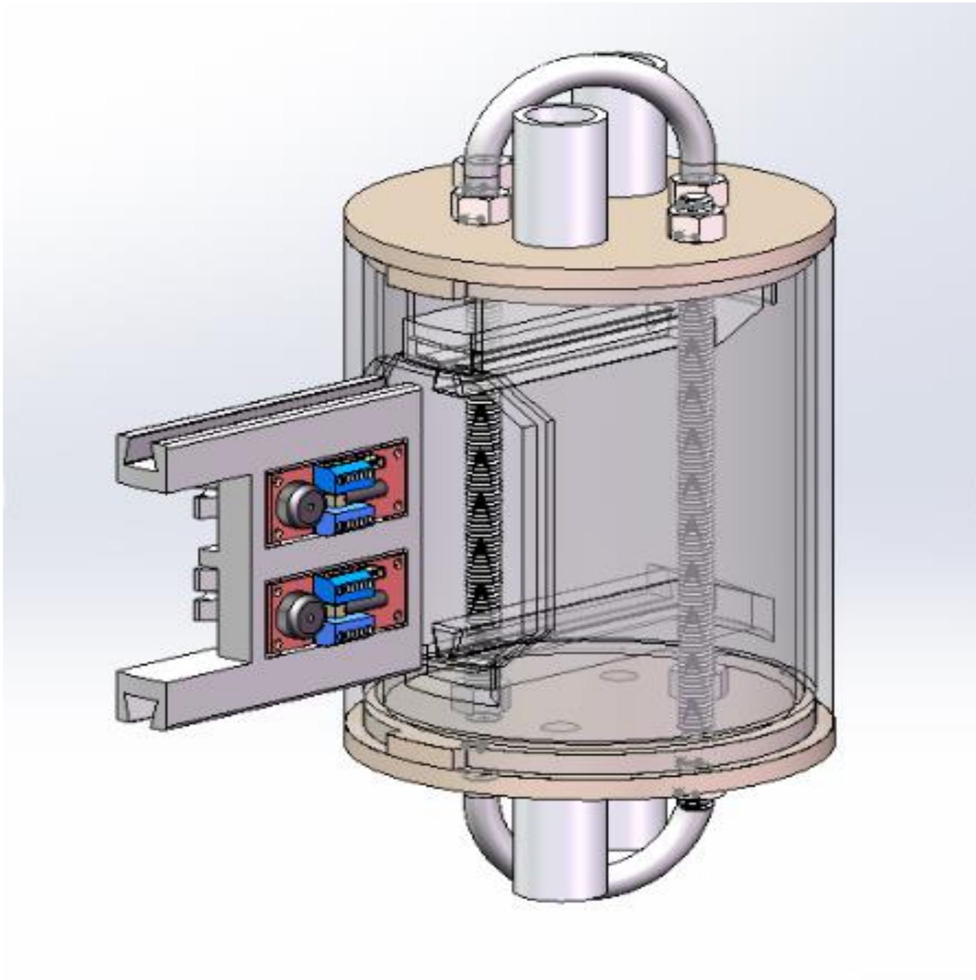


Figure 7. 2018 Avionics Bay

On the tray inside the avionics bay there will be two fully independent systems composed of a Stratologger CF altimeter, a 9V battery, and initiators. The wiring schematic for the two systems is shown in Figure 8. The wires running from the altimeters to the ejection charges will pass through two holes drilled in each bulkhead on either end of the AV bay.

To prevent a premature completion of the electrical circuit, the wires that connect the altimeters to the initiators will have quick snap connectors, labeled as the switch in Figure 8. These will be kept disconnected until the rocket is completely assembled and safely on the launch rail.

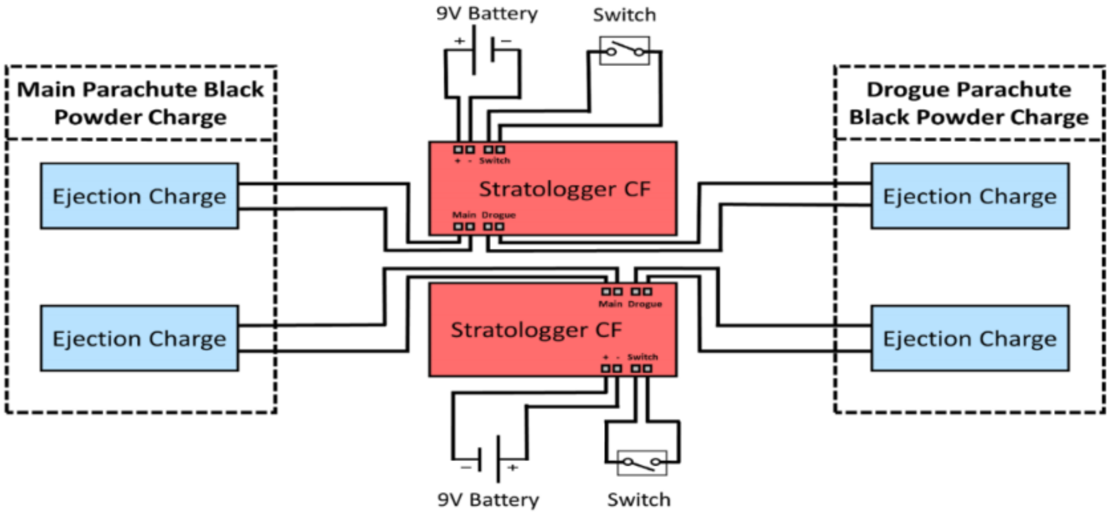


Figure 8. Avionics Bay Wiring Diagram

Technical Design Challenges

A major technical challenge for this year's rocket is managing and keeping the third separation point of the rocket intact during main parachute deployment. This third separation point is due to the rover payload which must be deployed on the ground. Payload will design the nose cone deployment system independent of the rover to avoid rover interference causing separation. However, when the main parachute deploys, it induces a jerk which has the possibility of causing the shear pins to break if the force created is high enough or if there are not enough shear pins. This can be mitigated by ensuring that there is a proper amount of shear pins that will not break when main deploys. Due to this, the team must complete extensive testing on the shear pins to determine what a safe amount to use will be during launch. In the previous year's rocket, there were numerous issues determining the shear pin count. A CO_2 ejection system was originally designed to deploy the nose cone, but had to be replaced with a black powder ejection charge after testing determined that the CO_2 system produced an insufficient amount of force to break the nose cone shear pins. To negate the risk of premature deployment, the team must complete shear pin testing, and use full scale test flight as final verification to ensure that the chosen number of shear pins will withstand forces during flight.

4.4 Payload

Technical Design

The payload team will design and construct an autonomous rover to perform a soil sample recovery.

Because the team built a similar payload last year, a lot of the design decisions are going to be modeled from the previous rover. The team decided that building off the successful components of last year's design and improving upon the failures would provide the best results this year.

The most critical deficiency of last year was the deployment mechanism. The rover was deployed prematurely from the rocket due to a short circuit. To solve this issue, the deployment mechanism will be independent of the rover itself, and it will be tested more rigorously. Once the rocket has landed, a black powder charge will separate the nose cone from the body tube to allow the rover to drive out. The deployment circuit will consist of an Arduino, a LoRa RFM9x radio module, and an ignitor mounted to a shelf inside of the containment mechanism. Simplification of the separation circuit will mitigate the risk of failure.

Another problem with the previous year's design was the clearance between the ground and the bottom of the body. To solve this issue, the amount of material on board the rover will be minimized. Removing the deployment mechanism from the rover is one decision that will aid in minimization. Additionally, the rover will run two dual shaft DC motors instead of 4 single shaft motors. This will reduce the amount of space inside the rover as well as the number of pins needed on the microcontroller. Lessening the number of pins would reduce the size of the microcontroller needed.

However, the largest contribution to the clearance issue of last year's design was the vertical symmetry. The rover was designed to be able to drive either right side up or upside down since the orientation of the rocket upon landing was unknown. The symmetry design decision eliminated a lot of the clearance. To solve this issue, the team is designing a rotating containment mechanism to ensure the rover's orientation will be upright upon landing. The rotating containment mechanism will be printed on the team's 3D printer using PLA plastic. This is a better fabrication method because it will allow a high level of construction tolerances that would not be achievable when constructing by hand. The shelves will be used to store the deployment mechanism as well as constraining the rover during flight. One of the issues with last year's shelf design was that it was constructed by hand; therefore, it was difficult to get the shelves perfectly aligned. When using a 3D printer, the accuracy is as good as the tolerances on the printer used. An isometric image of the containment mechanism design is shown in Figure 9 below. The system will be flush with the inside of the rocket and attached to the bulkhead at the end of the payload section. The blue portions of the system will be 3D printed and the shelves will be constructed from either fiberglass or wood.

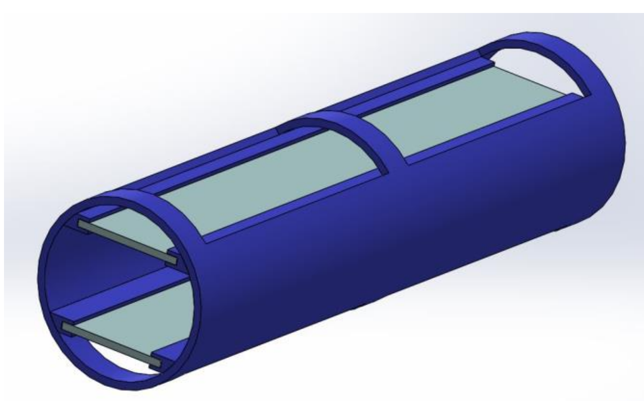


Figure 9. Payload Containment Mechanism

The preliminary design choice for how to do the soil sample recovery is a servo powered scooping mechanism. Further design considerations and testing will need to be performed before any final decisions are made.

Table 3 below is a table outlining the design choices for the rover's body material. The table includes the description of the material for the rover's body and the considerations that will be made to create a design matrix later in the semester.

Table 3. Material Considerations for Rover Body

Rover Body Material	Description
PLA Plastic	Fabricate the body from plastic filament via additive manufacturing. This option is considered because it would simplify construction, and cut down on overall weight.
Fiberglass	Fabricate the body from a sheet of fiberglass. This option is considered because it would be sturdy, easy to screw into, and is readily available in the lab.
Wood	Fabricate the body from a sheet of wood. This option is considered because it would be cheap and easy to work with.

Technical Challenges

Learning from the challenges the team faced designing last year's rover, the most important and potentially the most difficult challenge to overcome will be creating a rover that will have enough clearance to move across the tilled soil in Alabama. This will require the team to minimize the amount of space needed for the body of the rover while still keeping within the dimensions of the body of the rocket's payload bay. To overcome the challenge, the team will need to focus on testing the different body styles to keep within the constraints and still have enough room for the electronics within. Similarly, the team will also need to work on prototyping the rover, starting with the most basic electronic components and then potentially adding more if space allows. The key to overcoming this challenge will be keeping the electronic components of the rover to a minimum to save space and maximize clearance.

Another important challenge that the team must account for is the tread on the tires. The previous rover had very minimal treading to keep the tires small and fit within the tight constraints of the rocket body. The rover did successfully fit within the small dimensions, but the lack of treading severely limited the rover's ability to move on the loose soil that makes up the field in Alabama. While the constraints are similar this year, the team needs to put time in to creating multiple different tire designs that could dig into the ground and keep the wheels from spinning. Again, prototyping with a bare-bones rover will give the team great insight into which wheels achieve the best traction. It will be paramount that the team rigorously tests the different designs in similar conditions to those in Alabama to design the best wheels for the rover.

The containment mechanism will be a large challenge for the team again this year. To reduce the size and weight of the rover, the team plans to keep the containment mechanism and electronics completely separate from the rover. To make sure the system is fail safe, the team will need to test the containment system using different shock tests to simulate the shock that will occur during the flight and landing of the rocket. Similarly, the team will test the black powder charges with the electronic components in the payload pay to make sure there will not be any short circuiting or damage done by the jolt or the black powder soot.

5. Educational Engagement

5.1 Team Involvement

To keep other people of the community involved, LTRL participates in many outreach events during the school year. Many of these events are taken place in State College and team members' hometowns where LTRL members show their excitement in their STEM field in hopes to motivate people of all ages to become involved with science and technology. During these events, team members go to elementary schools, middle schools, and high schools to display LTRL's past Student Launch rockets. Team members disassemble the rocket to show pieces of the rocket such as the avionics bay, the rover, and where the parachutes go on launch day. For younger students, club members set up a competition for balloon races to explain propulsion. For older students, the team has the engaged students build drinking-straw rockets to show the effectiveness of fins for stability.

All LTRL members interested in traveling to Huntsville, Alabama for the Student Launch competition in April are required to attend at least three outreach events. The public relations/outreach chair will be responsible for setting up these events and for making a packing list of supplies that needs to be taken to the event. The team does not bring black powder or rocket motors to any of these events since the team does not hold any demonstration launches since the locations the club presents at are not authorized launch sites.

6. Project Plan

6.1 Gantt Charts

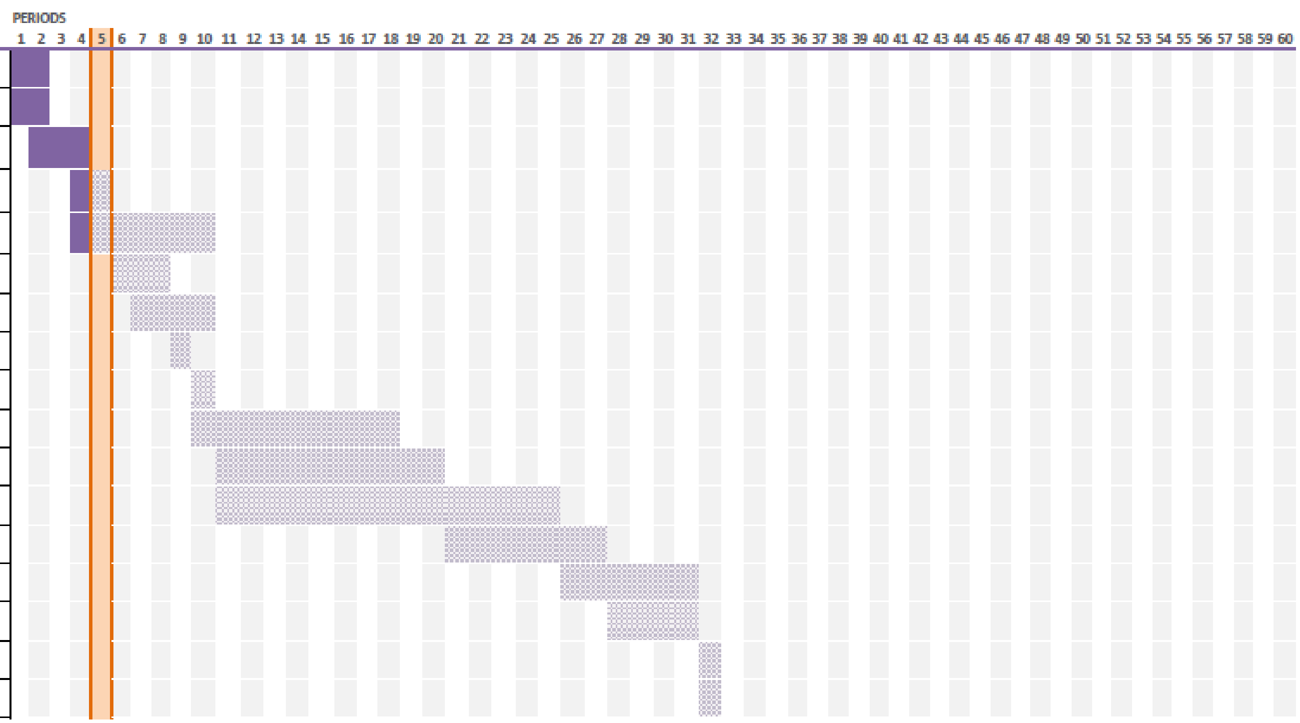
LionTech Rocket Labs Gantt Chart

LionTech Rocket Labs

LionTech Rocket Labs 2018-2019 Student Launch Gantt Chart

Period Highlight: 5 | Plan Duration | Actual Start | % Complete | Actual (beyond plan) | % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Fullscale Initial Design	1	2	1	2	100%
Payload Initial Design	1	2	1	2	100%
Proposal	2	3	2	3	100%
Subscale Design	4	2	4	1	50%
Payload Design	4	7	4	1	20%
Subscale Construction	6	3	0	0	0%
PDR	7	4	0	0	0%
Subscale Flight	9	1	0	0	0%
Redesign	10	1	0	0	0%
CDR	10	9	0	0	0%
Fullscale Testing &	11	10	0	0	0%
Payload Construction	11	15	0	0	0%
FRR	21	7	0	0	0%
Payload Integration	26	6	0	0	0%
Competition Preparation	28	4	0	0	0%
LRR	32	1	0	0	0%
Competition Launch	32	1	0	0	0%



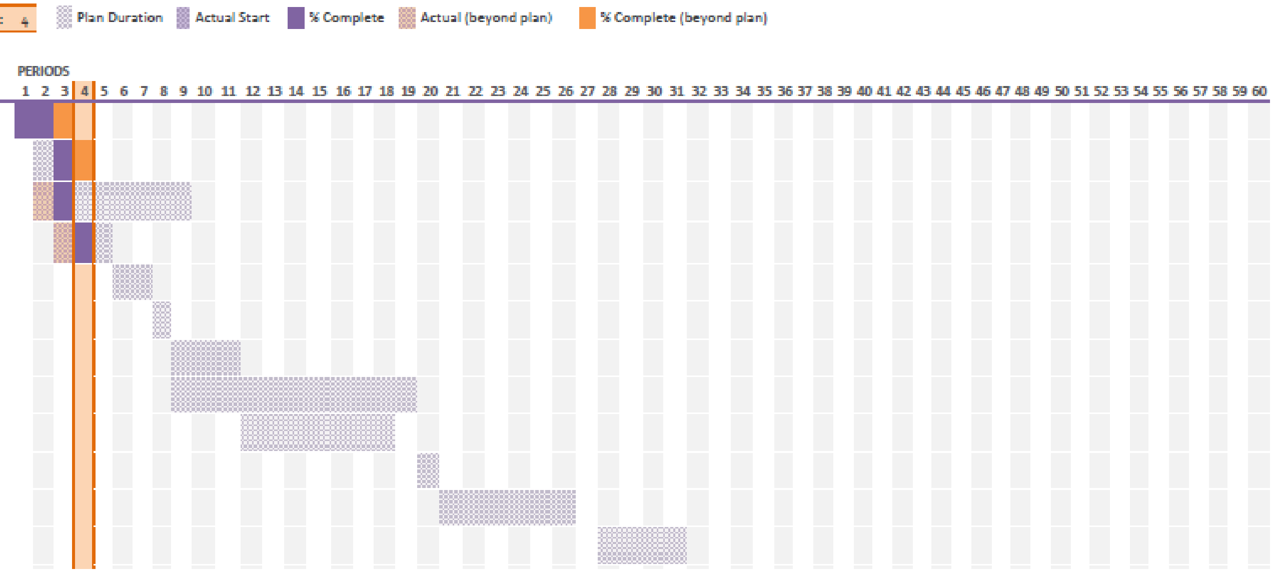
Structures and Propulsion Gantt Chart

LionTech Rocket Labs

Structures/Populsion 2018-2019 Student Launch Gantt Chart

Period Highlight: 4

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Proposal Design	1	2	1	3	100%
Proposal Writing	2	2	3	2	100%
Fullscale Design	3	7	3	0	25%
Subscale Design	4	2	4	0	50%
Subscale Construction	6	2	0	0	0%
Subscale Flight Analysis	8	1	0	0	0%
PDR Writing	9	3	0	0	0%
Fullscale Construction	9	11	0	0	0%
CDR Writing	12	7	0	0	0%
Fullscale Flight Analysis	20	1	0	0	0%
FRR Writing	21	6	0	0	0%
Competition Preparation	28	4	0	0	0%

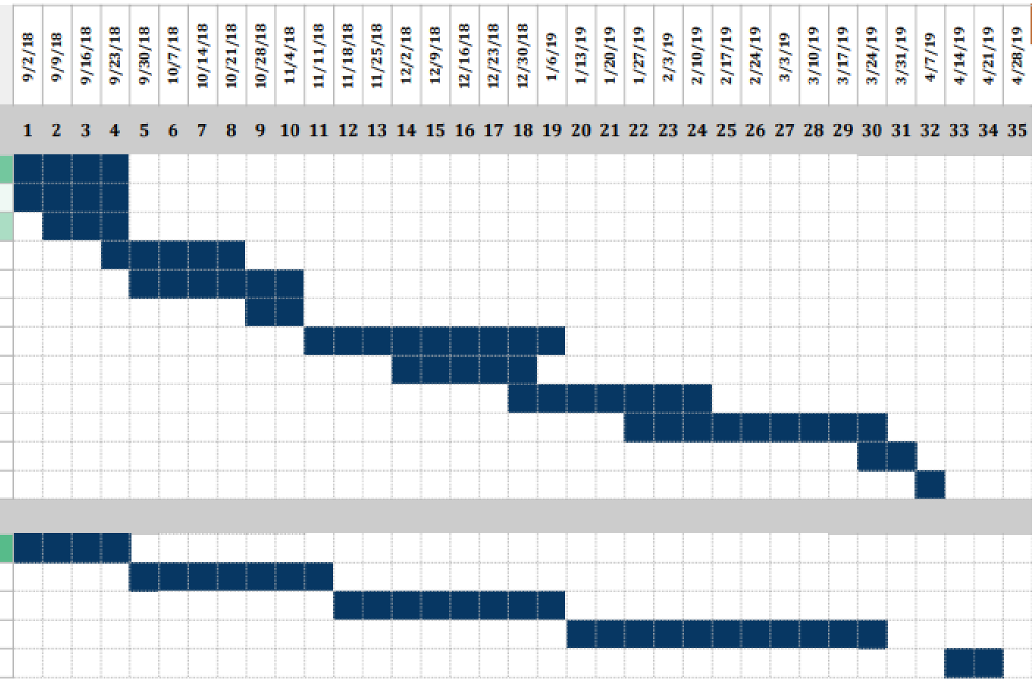


Avionics and Recovery Gantt Chart

Avionics and Recovery

2018-2019 USLI Gantt Chart

Technical Builds	Plan Start	Plan Duration	Actual Start	Actual Duration	Completion
Preliminary Recovery System Concept			NA		80%
Subscale AV Bay Design			NA		10%
Subscale Parachute Selection			NA		50%
Subscale AV Bay Construction			NA		0%
Subscale Recovery System Testing			NA		0%
Final Subscale Recovery System Verification			NA		0%
Fullscale AV Bay Desgin			NA		0%
Fullscale Parachute Selection			NA		0%
Fullscale AV Bay Construction			NA		0%
Fullscale Recovery System Testing			NA		0%
Final Fullscale Recovery System Verification			NA		0%
USLI Launch			NA		0%
Reports					
Proposal	0				99%
PDR	0				0%
CDR	0				0%
FRR	0				0%
PLAR	0				0%



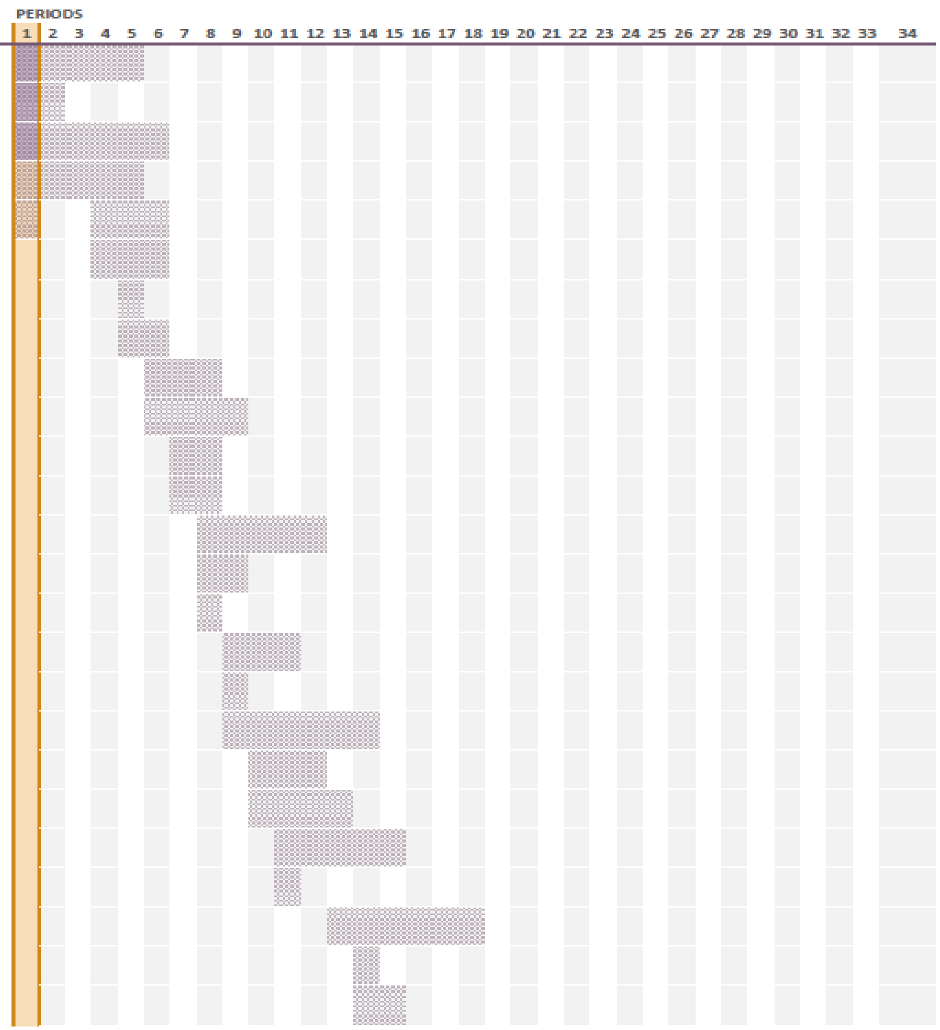
Payload Gantt Chart

Payload Systems Gantt Chart

Select a period to highlight at right. A legend describing the charting follows.

Period Highlight: 1 | Plan Duration | Actual Start | % Complete | Actual (beyond plan) | %Complete(beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Conceptualization	1	5	1	1	0%
Proposal	1	2	1	1	0%
Equipment Selection	1	6	1	1	0%
Electronics Container	2	4	1	1	0%
Motor Selection	4	3	1	0	0%
Preliminary Testing	4	3	0	0	0%
PDR	5	1	0	0	0%
Drive Train Design	5	2	0	0	0%
Frame/Suspension Design	6	3	0	0	0%
Tread Design	6	4	0	0	0%
Soil Collection Mechanism	7	2	0	0	0%
Flowchart/Identify	7	2	0	0	0%
Assembly of Rover	8	5	0	0	0%
Telemetry System Integration	8	2	0	0	0%
Complete Software	8	1	0	0	0%
Test/Review Modules	9	3	0	0	0%
CDR	9	1	0	0	0%
Design/Build Containment	9	6	0	0	0%
Consolodate Modules	10	3	0	0	0%
Test Subsystems of Rover	10	4	0	0	0%
Test Full Assembly of Rover	11	5	0	0	0%
FRR	11	1	0	0	0%
Pre Launch Modifications	13	6	0	0	0%
USLI Competition	14	1	0	0	0%
PLAR	15	0	0	0	0%



6.2 Budget

Table 4. Expected Outflow for 2018-2019

Purchase Category	Cost
Full Scale Construction	$2,800.00
Subscale Construction	$1000.00
Testing	$500.00
Travel (hotels, vans, etc.)	$8,000.00
Outreach	$200.00
Miscellaneous Equipment	$1,000.00
Total	$13,500.00

Table 4 outlines the different sources of club expenditure anticipated for the 2018-2019 academic year in the Student Launch competition. Full scale construction includes the costs of all materials necessary to construct the full scale launch vehicle including the necessary propulsion motors. Subscale construction accounts for the costs of all materials necessary to construct the subscale test launch vehicle including the necessary propulsion motors. Testing covers the cost of performing materials testing on possible launch vehicle materials such as purchase multiple forms of materials to decide the flight vehicle's material. Travel costs consist primarily of the expenses necessary to travel to and stay in Huntsville, Alabama for the week of the Student Launch competition. Travel costs also include fuel reimbursements for traveling to test launch locations. Outreach includes the cost of developing demos for display at the outreach event as well the cost of fuel to drive to the event. Miscellaneous equipment encompasses any tools, equipment, and supplies needed to accomplish LTRL's goal.

6.3 Funding

Table 5. Expected Inflow for 2018-2019

Source of Funds	Received Funds
Penn State College of Engineering	$1,000.00
Penn State Aerospace Engineering Department	$2,000.00
Penn State Mechanical Engineering Department	$1,500.00
University Park Allocations Committee (UPAC)	$7,000.00
Club Fundraising	$1,000.00
Pennsylvania Space Grant	$2,055.37
The Boeing Company	$500.00
Total	$15,055.37

Table 5 shows the sources of funding that LTRL plans to use during the 2018-2019 academic year. The Penn State College of Engineering has repeatedly supported LTRL and is expected to do so again. The Penn State Department of Aerospace Engineering aerospace engineering consistently supports LTRL's goals and high number of aerospace engineering student members. The Penn State Department of Mechanical Engineering shows support for the mechanical engineering student members of LTRL. University Park Allocations Committee (UPAC) is a Penn State organization that supports the clubs at Penn State. They offer funding to LTRL to cover most of the expenses related to travel and large equipment purchases such as a 3D printer. Club fundraising is represented largely by the club's required dues to become a member.
The Pennsylvania Space Grant offers the club support in recognition of furthering STEM involvement in NASA related fields. Each year the Boeing Company offers funds in support of LTRL's mission.

In order to prevent any unseen expenses from impacting the club's performance LTRL will be pursuing as much additional funding as possible. Additional funds may be available from the Pennsylvania Space Grant if those funds are depleted. The club will be attempting to collaborate with corporate sponsors such as the Boeing Company to acquire additional funding.

Having extra funds available to the club will allow the club to set more goals and expand current goals. Extra funds will allow participation in other projects such as supporting club members to acquire their level 1 and 2 certifications through the National Association of Rocketry. This is important to the club since LTRL needs current members to have proper certifications to launch the subscale and full scale rocket.

6.4 Sustainability

LTRL sets one of its goals as to be active within the Penn State community. As the team's members come from an assortment of majors throughout the STEM field, LTRL has built relationships with many different departments that help with recruitment and/or funding. Penn State's Aerospace Engineering Department, Mechanical and Nuclear Engineering Department, Electrical Engineering and Computer Science Department, and the College of Engineering are the main departments that the club regularly updates throughout the year. The club tries to maintain a relationship with these Penn State departments in between reports, so they can see how their funding is essential to LTRL. The club also takes advantage of being able to ask faculty for technical and administrative guidance.

LTRL is always actively growing. The team is represented at several involvement fairs every semester to find new, interested students. LTRL ensures to retain its current members as well because experienced members are essential to this project. In order to keep everyone involved, LTRL has members engaged during meetings by being a part of the designing, building, and testing processes of the competition. To help see where the members' work is going, the team takes general body members to launches throughout the academic year.

7. Appendices

7.1 Appendix A: Hazard Analysis

By examining the expected human and environmental interactions with the rocket, many different hazards have been identified. All hazards have been assigned a risk value through the use of a risk assessment matrix, which can be found in Table 6 by evaluating likelihood that the hazard will occur and the severity of that hazard. Each of these hazards have been assigned a combined risk factor by combining their severity score and their likelihood score. To determine the likelihood of every hazard, a score from 1 to 5, with a score 1 being the highest, was given. To accurately give a likelihood score, the following conditions were taken into account:

- All team members have undergone proper lab safety training and understand how to properly use the equipment
- All team members understand when they are required to wear PPE and how to properly use the PPE to prevent harm
- All team members understand all rules set forth in the safety manual and any laws and regulations that may be in place relating to the project at hand
- All procedures were correctly followed during testing, launching, and construction of the rocket
- Any equipment was properly inspected before use and if determined inadequate, was properly disposed
- Any component used during testing, launching, or construction of the rocket was properly inspected before and if determined inadequate was either properly disposed of or replaced to ensure a safe build of the rocket for any tests or launches

The criteria for the selection of the likelihood value is outlined below in Table 6.

Table 6. Likelihood Value Criteria

	Likelihood	
Description	Corresponding Value	Criteria
Almost Certain	1	Greater than a 90% chance the hazard will occur
Likely	2	Between a 90% and 50% chance the hazard will occur
Moderate	3	Between a 50% and 25% chance the hazard will occur
Unlikely	4	Between a 25% and 5% chance the hazard will occur
Improbable	5	Less than a 5% chance the hazard will occur

A severity value has been assigned from 1 to 4 for all hazards, with a value of 1 being the most severe. To determine the severity value for each hazard, a set of criteria has been established based on injuries, damage to any equipment and/or the rocket, and any possible environmental damage, which will be compared to the possible outcome of the hazard or issue. This criteria can be found below in Table 7.

Table 7. Severity Value Criteria

	Severity	
Description	Corresponding Value	Criteria
Catastrophic 2 Could result in severe injuries, significant but reversible environmental effects, partial mission failure, or monetary loss of $500 or more but less than $5k.	1	Could result in any number of deaths, irreversible damage to the environment, mission failure, or monetary loss upwards of $5k.
Critical	2	Could result in severe injuries, many moderate environmental impacts or a severe but reversible environmental impact, partial mission failure, or monetary loss between $500 and $5k.
Marginal	3	Could result in minor injuries, a number of minor environmental effects or one moderate one, a complete failure of non-mission essential system, or a monetary loss between $100 and $500.
Negligible	4	Could result in insignificant injuries, a minor environmental impact, a partial failure of a non-mission essential system, or monetary loss of less than $100.

By using the likelihood value and the severity value, an appropriate risk level has been determined and assigned using the risk assessment matrix found in Table 8. The matrix identifies all combinations of severity and likelihood as either, low, moderate, or high risk. The team's goal is to have all hazards to be at a low risk designation before competition launch. All of the hazards that are currently above low risk will be reexamined and investigated to increase the mitigation through additional or better safety procedures, practices or verifications to reduce the overall risk value.

Currently, preliminary risk assessments have been conducted for possible hazards throughout testing, launching, and constructing the rocket. By identifying these hazards early on, the team can take the appropriate caution when dealing with these hazards to ensure that proper safety protocols are followed. As the team progresses throughout the design, more hazards will arise that need to be carefully identified and mitigated. Once testing has been performed, risk levels may be lowered as necessary. Currently, all identified hazards can be found in Appendix B.

Table 8. Risk Assessment Matrix

			Risk Assessment Matrix	
		Severity Value		
Likelihood Value	1-Catastrophic	2-Critical	3-Marginal	4-Negligible
1-Almost Certain	2-High	3-High	4-Moderate	5-Moderate
2-Likely	3-High	4-Moderate	5-Moderate	6-Low
3-Moderate	4-Moderate	5-Moderate	6-Low	7-Low
4-Unlikely	5-Moderate	6-Low	7-Low	8-Low
5-Improbable	6-Low	7-Low	8-Low	9-Low

Lab and Learning Factory Risk Assessment

During the construction and manufacturing of components for the rocket, there will be many risks associated. All of this construction and manufacturing will be conducted either at the Learning Factory or the LTRL Lab. The hazards assessed from working with machines, tools, or chemicals can be found in Table 10.

Launch Vehicle Assembly and Risk Assessment

The hazards found in Table 11 are hazards that could be encountered during the launch of the vehicle or the assembly of the vehicle.

Propulsion and Stability Risk Assessment

Propulsion and Stability Risk Assessment
Because the team is buying commercially produced motors, this area is of lower risk than if team produced its own motors. There are still risks associated, however. The team plans on allowing only members who have proper motor level certifications to use, handle, purchase, and work with the rocket motors. The team plans on accurately producing a stable rocket that can handle the rocket motor the team chooses. All hazards associated with propulsion and stability are found in Table 12.

Avionics and Recovery Risk Assessment

Because LTRL is required by NASA to use dual deployment, many of the hazards stated would be possible for all of the systems. To be concise, all the stated hazards will only be stated once. The hazards that are associated with avionics and recovery can be found in Table 13.

Environmental Hazards to Rocket Risk Assessment-

The hazards found in Table 15 are risks that the environment could impact the rocket or a component of the rocket. Unfortunately, the team has no control over environmental hazards and cannot reduce the risk of the hazard. Because of this, these hazards can be considered outside of the team's ideal scenario of having all hazards be at a low risk level. To ensure proper safety, if the environment poses a moderate risk to the rocket or a component of the rocket, the launch will be delayed until the Safety Officer lowers the risk level to low and approves the team to consult the Range Safety Officer to see if it is safe to launch.

Hazards to the Environment Risk Assessment

During construction, testing, or launching of the rocket there may be hazardous to the environment. The associated hazards can be found in Table 16.

7.2 Appendix B: Safety Risk Assessments

Table 9. Overall Team Risk Assessment

Overall Team Risk Assessment						
Hazard	**Cause/Mechanism**	**Outcome**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Project falls behind schedule	Major milestones are not met in time	Team cannot compete in Alabama.	1	4	5-Moderate	Weekly status meetings, follow project plan and Gantt chart
Project is over budget	Project requires more money than allotted	Team fails to complete the project and cannot compete in Alabama.	1	4	5-Moderate	Properly allot resources over time and provide communication with the treasurer, the school, and the subsystems.
Club loses facilities	Room 46 Hammond no longer available	The club no longer can build the rocket.	1	5	6-Low	Maintain clean environment and proper storage of materials along with maintaining a good relationship with the University.
Damage during test flights	Failure of recovery devices or motor retention	Team falls behind and has to rebuild the rocket entirely.	2	5	7-Low	Ground testing and testing on all parts along with simulations of the rocket flight
Injury of Team Personnel	Team member become hurt while working on project	A team member could suffer a severe injury that causes long recovery.	2	5	7-Low	Identify potential safety hazards. Inform and enforce team safety.

Integration Failure	Parts don't fit together properly	The rocket may not be safe for launch.	2	5	7-Low	Shared online documents and testing of parts and necessary sanding.
Club loses funding	One or more sources can no longer provide funding	The team may become strapped for resources and money.	3	4	7-Low	Dedicated members to track expenses and make funding contacts.
Failure to acquire transportation	Transportation to Alabama cannot be acquired	The team cannot secure vans to travel down to Alabama.	3	4	7-Low	Have a plan to carpool if necessary.
Labor leaves/graduates	Seniors graduate or students stop attending meetings	Loss of leadership and manpower leads to the team falling behind schedule.	3	4	7-Low	Recruitment at beginning of each semester along with team building activities.
Parts are unavailable	Testing or fabrication parts are not available when needed	Project falls behind and has to make up ground.	4	3	7-Low	Use non-exotic materials and check for availability. Order parts far in advance or order parts from different places.
Theft of Equipment	Parts or testing equipment get stolen	Loss of parts and team has to remake those parts.	4	5	9-Low	Only subsystem leaders and officers will have card access to the LTRL lab.

Table 10. Lab and Learning Factory Risk Assessment

Lab and Learning Factory Risk Assessment						
Hazard	**Cause/Mechanism**	**Outcome**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
High Voltage Shock	Improper use of welding	Severe injury or even death	1	5	6-Low	All members must have certified training prior to welding. Two certified team members will be present when welding.
Using machines or power tools such as saws, sanders, drills, or blades	Improper use of the tool or lab equipment from poor training	Possible burns or cuts to team members. The rocket or tool may also be damaged.	2	4	6 - Low	All members using the tool must have knowledge and training with using that tool. If they are using the tool for the first time, they shall be taught properly by a lead or executive member and then watched to make sure they properly follow procedure. Additionally, all members are required to wear safety glasses in the lab. Finally, if applicable, a vacuum will be placed near the point of cutting or drilling to ensure particulates or shards are properly disposed of.
Working with chemical components	Chemical splash or fumes	Possible mild to severe burns or asthma aggravation due to inhalation of fumes.	2	4	6-Low	MSDS data sheets will be available to all members in the lab. Additionally, all team members must understand the risks that the chemical poses. All members will also wear nitrile gloves and have proper clothing.
Sanding materials	Improper use of PPE	This could cash a rash, a sore throat, nose, eyes, and possible asthma.	3	3	6-Low	All individuals will be required and taught how to use proper PPE during sanding and using other tools. Additionally, team members will have to wear long sleeves and long pants.

Metal shards	Using a drill or other cutting equipment to machine metal parts	Metal splinters lodged in the skin or in the eyes.	2	5	7-Low	When entering the lab, all team members must have closed toe shoes, long pants, long sleeves, wear gloves when machining, and wear safety glasses. If applicable, a vacuum will be placed near the place of cutting or drilling
Use of white lithium grease	Used when installing the motor	Possible skin irritation	3	4	7-Low	All members will be required to wear gloves and safety glasses when working with hazardous substances.
Burns while soldering	Improper use of the soldering iron	Minor to severe burns	4	3	7-Low	All team members will be taught how to properly solder and will be supervised by an experienced member.

Table 11. Launch Vehicle Assembly Risk Assessment

Launch Vehicle Assembly Risk Assessment						
Failure	**Cause**	**Effect**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Fin Separation from fin brackets	Loosening of bolts in fin brackets due to excess vibrations experienced during launch, flight, parachute deployment, descent, and landing.	Potential free-falling sky debris	1	5	6-Low	The fin brackets will be inspected prior to and following each flight.
Fin bracket fracture	Extreme or repeated impact, bending moment	Aerodynamic instability, structural failure, potential free-falling sky debris	1	5	6-Low	The fin brackets have been designed for structural strength. They slide into slits in the body tube, utilizing the added strength of the carbon fiber to form a secure and structurally sound attachment. The fin brackets will be inspected prior to and following each launch for any sign of structural instability.
Eye Bolts Separation from bulkheads	Extreme stress from shock cord or insufficient thread strength on bulkhead. Loosening of eye bolt due to excess vibrations during launch, flight, parachute deployment, descent, and landing.	Complete failure of parachute deployment, potential free-falling sky debris	1	5	6-Low	All eye bolts will be securely fastened to their bulkheads using a washer and nut. The nut will be tightly fastened using a wrench before each launch. Eye bolts will only be purchased from trusted manufacturers, and will be inspected before every launch for potential defects.

Bulkhead Separation from body tube	Insufficient Epoxy strength	Complete failure of parachute deployment, potential free-falling sky debris	1	5	6-Low	All bulkheads will be epoxied onto couplers that shock cord will run through. During separation events, large forces experienced by the bulkhead from parachute deployment will be absorbed by not just the epoxy of the bulkhead to the rocket, but also by the epoxy to the bulkhead, and fasteners connecting the coupler to the body tube. Prior to and following each launch, the bulkheads will be inspected for signs of separation from the rocket.
Crack along inner/outer seam of body tube	Extreme torsional stress or bending moment due to extreme rotational acceleration.	Functional/Structural inadequacy	2	4	6-Low	Due to the nonhomogeneous nature of the frame material, FEA simulations do not provide accurate results. To mitigate this issue, components were verified before and after full scale test launch to verify any surface defects, cracks, or other abnormalities that may appear.

Unwanted coupler separation from body tube	Premature shear pin fracture due to extreme axial or torsional stress caused by extreme jerk or excess rotational acceleration.	Undeployed parachutes, incorrectly timed parachute deployment, incorrect descent	3	3	6-Low	Simulations of the most extreme cases expected will be conducted. Shear pin locations will be optimized using stress analysis so that a minimum value of shear pins can be employed. Total shear pin stress resistance will be rated at a minimum of 1.2 times the maximum stresses simulated.
Coupler Fracture crack	Extreme torsional stress or bending moment due to extreme rotational acceleration.	Aerodynamic inconsistency/Structural Failure	3	3	6-Low	The couplers will be inspected before and after each launch in order to verify that the couplers are in good working condition. Fireballs and proper shock cord length assignments will be used to reduce the occurrence of extreme torsional stress on the coupler.
Coupler/Body Tube Zippering	Extreme sudden stress from shock chord when parachute deploys.	Structural Failure, potential sky debris	4	2	6-Low	Implementation of proper fireball use. Reinforcing location(s) of the rocket where highest probability of zippering is expected to occur.
Premature nose cone separation	Premature shear pin fracture due to extreme axial or torsional stress caused by extreme jerk or excess rotational acceleration.	Aerodynamic inconsistency/ Instability, sky debris	2	5	7-Low	Verify that premature nose cone separation will not occur with extensive testing of shear pins. Will verify number of shear pins will withstand forces experienced during flight with full scale test flight.

Cascading Fracture of body tube	Extreme stress due to sudden change in acceleration due to takeoff, parachute deployment, and landing localized around bolt hole.	Functional/Structural inadequacy	2	5	7-Low	Due to the nonhomogeneous nature of the frame material, FEA simulations do not provide accurate results. To mitigate this issue, components were verified before and after full scale test launch to verify any surface defects, cracks, or other abnormalities that may appear.
Bulkhead Fracture crack	Material Defect, stress on eye bolt threads	Structural Failure, pressure leakage, potential failed parachute deployment	2	5	7-Low	Plywood bulkheads were used in order to take advantage of the structural strength of the plywood. Holes were carefully drilled so as to reduce the incidence of splitting. The bulkheads will be examined prior to and following each launch for any signs of splitting or other structural instability.
Fin fracture crack	Extreme or repeated impact, bending moment	Aerodynamic instability, Structural failure	3	4	7-Low	Due to the nonhomogeneous nature of the fin material, FEA simulations did not provide accurate results. To mitigate this issue, components were verified before and after full scale test launch to verify any surface defects, cracks, or other abnormalities that may appear.

Body tube Fracture crack	Material Defect, Repeated impact	Aerodynamic inconsistency/Structural Failure	3	5	8-Low	A visual inspection will be conducted for each piece of the body tube before and after each launch/landing cycle. If any parts are damaged beyond repair, a new replacement part will be fabricated.

Table 12. Propulsion Risk Assessment

Propulsion Risk Assessment					
Hazard	**Cause**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Motor CATOs	Catastrophic motor failure during launch	1	5	6-Low	Inspect motor grains prior to installation. Have a certified member assemble the motor with another member observing.
Motor does not stay retained	Ejection charges push motor out rear of rocket	1	5	6-Low	Ensure that motor retention system uses sufficient epoxy and centering rings to retain motor during launch. Will install motor block above motor tube to prevent motor from violently launching through entire launch vehicle if motor retention system fails.
Igniter does not light motor	Motor either chuffs or does not light	2	4	6-Low	Use a properly sized igniter and cap the nozzle.

Table 13. Avionics and Recovery Risk Assessment

Avionics and Recovery Risk Assessment						
Description	**Cause**	**Effect**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Drogue or main parachute fails to exit the body tube and deploy	Friction prevents smooth exit, chute catches on something	Flight vehicle impacts ground with greater force than allowed	1	4	5-Moderate	Ensure proper packing on the ground, add baby powder to the inside of the tube. Will design launch vehicle so that no parachutes are being deployed into a full body tube.
Shock cord burns	Wadding was not sufficiently placed around the parachute.	Shock cord tears during descend separating sections of the body	1	4	5-Moderate	Choose a non-flammable, tested shock cord material.
Altimeter and backup altimeter fail to correctly register altitude	Altimeter was faulty, pressure did not adequately equalize in AV bay	Charges do not fire at the correct altitude to deploy the parachutes correctly	1	5	6-Low	Buy well researched altimeters and check for continuity in the altimeter before launching. Ground test the launch vehicle separation system before launch to ensure all avionics and recovery systems are working as intended.
Black powder fails to ignite	Charge was improperly packed, initiators failed or were improperly placed.	Rocket comes down at an unsafe velocity.	1	5	6-Low	Pack black powder tightly and check initiators before launch.

Altimeter sends premature signal to fire black powder	Circuit is completed by the jarring of the handling process.	Premature separation of rocket either during flight or while being handled club members, resulting in serious injuries.	1	5	6-Low	Do not arm altimeters switch until on the rocket is on the launch rail. Will not pack black powder into the avionics bay until right before launch. All members will not have their phones when putting the launch vehicle on the rail. Only essential personnel will load launch vehicle onto launch rail.
Quick links break	Exceeded force breaks the quick links.	The rocket tumbles at an unsafe velocity.	1	5	6-Low	Only use sufficient size quick links capable of withstanding shock cord forces.
Batteries in altimeter die	Batteries run out of charge.	Parachutes do not deploy.	1	5	6-Low	Use fresh, new batteries just before launch. Test for continuity of altimeter before launch.
Main chute and drogue tangle	Main chute deploys into drogue, sections tumble at similar velocities	Rocket descends at an unsafe velocity	2	4	6-Low	Make sure shock cords are different lengths
Parachute burns	Kevlar blanket was not sufficiently placed around the parachute.	Holes in parachute decrease drag coefficient or cause complete parachute failure, allowing rocket to descend too fast	2	4	6-Low	Wrap parachute in inflammable Kevlar blanket that will not be ignited by black powder charges.
Main deploys at apogee	Incorrect wiring or faulty altimeter	Rocket drifts further than allowed	3	4	7-Low	Double check wiring of altimeters before launch.

Table 14. Payload Risk Assessment

Payload Risk Assessment							
Failure	**Cause**	**Effect**	**Severity**	**Likelihood**	**Risk**	**Mitigation**	**Verification**
Rover ejection system prematurely fails	The ejection mechanism deploys prematurely	Nose cone of the rocket separates prematurely during flight, and cause free-falling body sections pose a serious danger to bystanders on the ground	1	3	4-Low	Perform thorough rigorous testing on the control software to prevent premature triggering	Tests have been written for the control software
Rover containment system fails during launch	Forces experienced during launch or landing	Rover becomes unsecured during launch. The rover could become damaged from forces experienced during flight. An unsecured mass could also cause instability during flight.	1	4	5-Moderate	Verify structural integrity of rover housing before launch. Ensure that materials used to construct rover containment mechanism can withstand launch acceleration.	Test that the rover and payload bay can withstand forces similar to those experienced during flight.
Structural damage to payload bay	Forces experienced during launch or landing	A breach in the wall of the body tube would prevent the black powder from creating enough pressure to separate the nose cone from the rocket body.	2	4	6-Low	Check parachute deployment mechanism with A&R subsystem to ensure that the rocket does not land a high rate of speed.	Verified with A&R subsystem that expected landing speed of the rocket does not damage rover.

Deployment mechanism fails to activate	Control software malfunction	Rover will be unable to deploy from the rocket.	3	4	7-Low	Perform rigorous testing on the control software to ensure that initiator is triggered, and test physical trigger method to ensure it works consistently.	Unit tests have been written for the control software.
Deployment mechanism fails to activate	Trigger mechanism becomes physically disconnected/damaged due to forces experienced during launch or landing	Rover will be unable to deploy from the rocket.	3	5	8-Low	Double check integrity of physical mount points for the activation trigger and soldered wires between the control board and trigger.	Test durability of trigger mechanism.
Deployment mechanism fails to activate	Faulty initiator	Rover will be unable to deploy from the rocket	3	5	8-Low	Use a multimeter to test the initiator before wiring it into the circuit.	Initiator testing has been written into launch procedure.
Physical damage to the rover	Forces experienced during launch or landing	Rover is damaged during launch or deployment. If damage sustained is severe enough, rover may be unable to operate correctly.	4	4	8-Low	Construct the rover out of materials durable enough to withstand launch forces. Construct robust rover retaining system to withstand forces experienced during flight.	Test that the rover can withstand forces similar to those experienced during flight.

Table 15. Environmental Hazards to Rocket Assessment

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause/Mechanism**	**Outcome**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Rain.	N/A	Unable to launch the rocket.	1	4	5-Moderate	The weather will be monitored to ensure cloud cover is not an issue. Multiple launch dates will be scheduled for test flights in case any dates are cancelled due to weather.
High winds.	N/A	The rocket has decreased launch altitude, drifts farther, or the launch could not occur.	1	4	5-Moderate	The weather will be monitored to ensure cloud cover is not an issue and the team can reschedule a launch if necessary. If the winds are deemed moderate, the team may still attend the launch and decide at the launch site if the weather is safe.

Trees.	N/A	The rocket may be damaged and the team cannot recover it.	1	4	5-Moderate	Drift calculations will be computed to ensure that the likelihood is decreased. Additionally, launching during high winds will not be allowed and the team can always change the launch angle if necessary.
Ponds, creeks, and other bodies of water.	N/A	The team could lose the rocket.	1	4	5-Moderate	Launching near any bodies of water should be avoided at all costs. Additionally, drift calculations can be done beforehand to ensure the rocket does not drift near a body of water.
Extremely cold temperatures.	N/A	Batteries could discharge resulting in avionics and payload failure.	1	5	6-Low	All batteries will be checked prior to all launches to ensure they are both in working condition and new.

Extremely high temperatures.	N/A	Heat could degrade electronics. Heat could cause unexpected discharging, or cause an explosion in LiPo batteries. Adhesives could degrade and lead to possible electrical malfunctions.	1	5	6-Low	The team will check the integrity of all electronics on launch day if temperatures are high enough to potentially degrade them.
Low cloud cover.	N/A	Unable to launch the rocket.	2	4	6-Low	The weather will be monitored to ensure cloud cover is not an issue and the team can reschedule a launch if necessary.

Table 16. Hazards to Environment Risk Assessment

Hazards to Environment Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Release of reactive chemicals.	Burning of composite motors.	Reactive chemicals released help contribute to the reduction of the ozone layer.	4	1	5-Moderate	The amount of reactive chemicals released by motors throughout the year would be negligible.
Release of toxic fumes in the air.	Burning of ammonium perchlorate motors.	Biodegradation.	4	1	5-Moderate	Small amounts will be burned that limit the damage to the environment.
Release of hydrogen chloride into the atmosphere.	Burning of composite motors.	Hydrogen chloride gets into the water and disassociates to form hydrochloric acid.	5	1	6-Low	The amount of hydrochloric acid released by motors throughout the year would be negligible.
Spray painting.	The rocket will be spray painted.	Water could be contaminated and emissions may be produced.	2	5	7-Low	All spray-painting operations will be performed in a small location away from water sources to limit the exposure to the environment.

Use of lead acid battery leakage.	Old or damaged housing to battery.	The battery acid will leak into the ground.	3	4	7-Low	The batteries being used are new and all manufacturer's instructions will be followed.
Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Could cause human illness if close to population.	4	3	7-Low	Batteries will be disposed of properly and when a spill occurs, proper procedure will be followed to ensure proper disposal.